NOTES ON THE CONTAMINATION OF A DRINKING AND RAILROAD WATER SUPPLY BY SEA WATER AND THE REMOVAL OF THE SALT WATER FROM THE RESERVOIR

By John R. Downes

Few incidents in the construction of the Panama Canal show more clearly the intricate complications which had to be met at every turn than that of the contamination of the Cocoli water supply by sea water.

Cocoli Lake was formed by the construction of the west toe of the Cocoli dam across the course of the Cocoli River. The water was diverted to the northward around the site of the Miraflores locks.

A shortage of water in the Rio Grande reservoir made it necessary to use these impounded waters of the Cocoli as an auxiliary to the water supply of the towns on the Pacific side of the divide, including Corozal, Ancon, Balboa and the native city of Panama.

When the pumping of silt from the sea level portion of the canal into core of the dam was begun, some uneasiness was felt by the sanitary department as to the effect of possible seepage of the salt water into the drinking water supply.

At the direction of the chief sanitary officer the writer, then in charge of the sanitation of the zone water supplies, kept a careful watch for any indication of the salt in the lake.

In spite of the fact that water from the lake had found its way through the toe of the dam into the core pit before hydraulic filling was begun, there was no corresponding flow in the opposite direction when the salt water was pumped into the core.

The average chlorine content of the lake water was 3 p.p.m. in October, 1910, 3.5 in November, 4.5 in December, 6 in January, 1911, the fill having been begun in September, 1910.

On November 1, 1910, fourteen samples were taken from the surface of the lake at intervals along the toe of the dam and eight samples from other parts of the lake. None showed more than 3.5 p.p.m. of chlorine.

Not until February 10, 1911, was there any marked increase in chlorine content of the lake. On this date the sample from the laboratory tap in Ancon showed a decided increase and an investigation at the lake resulted as follows:

Samples taken in a straight line across the lake at right angles to the toe of the dam showed p.p.m. Cl at the toe 94; one-fourth of the distance across 90; one-half the distance across 70; near the shore opposite to the toe 56.

On February 15 a slide occurred at the northeast corner of the lake (first point mentioned above). Samples were taken at intervals along the toe and along a parallel line extending through the center of the lake:

AT SLIDE NORTH END OF TOE	ALONG TOE	CENTER OF LAKE
Same as first point above (A).....	102	80
(B).....	78	78
(C).....	70	58
(D).....	70	60
South end of toe.....(E).....	58	

On February 20 a decided and sudden increase in the chlorine in Panama-Ancon tap water prompted another survey of the lake. Samples from points A, D, and E above contained 204, 208, and 202 parts of Cl respectively. Water from the pump, the intake of which was 9 feet below the lake surface, contained 358 p.p.m.

A report and warning were sent to the engineer in charge of the municipal work for the Pacific Division, who had been kept in touch with conditions constantly.

On the next day there was a vigorous protest from the transportation department, which reported all traffic in the Pacific Division delayed by the foaming of the boiler water. During the next few months serious trouble from foaming occurred whenever the chlorine went above 70 p.p.m.

On February 22 water containing 440 p.p.m. Cl was being pumped into the mains at Cocoli. Tap water in the city varied from 100 to 400 with the fluctuation in the quantity of water being supplied by the two sources, Cocoli and Rio Grande.

An emergency pumping station was set up on the Camatillo River, the only other available supply, but an unprecedented draught rendered this source pitifully inadequate.

The 16-inch main from Rio Grande was taxed to its limit and to increase the flow by an auxiliary main was not only too slow, but threatened to drain the reservoir before the end of the dry season.

The lock work at Miraflores and Pedro Miguel, the power house at Miraflores, transportation of the spoil trains from Culebra cut, the dock work at Balboa and the fire protection of the city were all at stake. There was absolutely no choice but to use salt water and make the best of it.

Locomotives, so far as possible, were watered in the other divisions or from the Rio Grande supply above the point of entrance of the Cocoli water. Of course there were strenuous objections from the public at the use of the brackish water, but even the international aspect, brought about by the remonstrances of the Panamanian government, could not be permitted to interfere with the progress of the canal, so the public drank the water and survived.

One curious incident nearly proved fatal. A surgeon who had been using the tap water, sterilized, for making injections in the treatment of syphilis, found one of his patients sinking rapidly under the influence of the salts on the patient's blood. He was able to bring the patient through, however, and thereafter the laboratory supplied distilled water for this use.

We were now confronted by two problems, to stop the leaks and to get rid of the salt already in our water supply. The first was accomplished without much difficulty by dynamiting the south end of the toe over the old river channel and reinforcing the south end where the slide had occurred, between an old fill and a new one, with a puddled core.

Investigation showed that large bodies of salt water had moved through the body of fresh water for distances of 1000 and even 1500 feet, finally settling in isolated deep holes where as much as 6000 p.p.m. of chlorine were found.

On March 25 the Pacific Division put into operation a 2,000,000-gallon pump with the intake at 13 elevation. The idea was to pump out the heavy salt layers from the bottom. The Cl in the discharge from the pump at 24-hour intervals follows:

March 25, 4250; 26, 3300; 27, 2500; 28, 2200; 29, 1950.

The writer suggested that the pump be run only 12 hours per day so as to permit the heavy salt layers to work towards the pump during the shut down. With constant running the upper layers with little salt in them found there way to the intake. The sugges-

tion being followed, the chlorine in the discharge fell to 1550 and remained at this point until the pump was removed on May 4.

On February 20 the chlorine had diffused across the lake and up into the river. The point where the river widens into the lake is about three-fourths of a mile from the leak and here the Cl was 29, while at the first falls in the river, a mile further up stream, it was 25.

Soundings were taken on the next day and the vertical distribution of Cl was found to be as follows:

ELEVATION ABOVE SEA LEVEL	CHLORINE; PARTS PER MILLION	APPROXIMATE QUANTITY OF WATER IN GALLONS
36.00	420	
31.00	420	
26.00	480	
25.75	520	254,000,000
25.50	600	
25.00	600	
24.50	680	
23.50	750	67,000,000
21.00	920	
18.00	1,300	33,500,000
13.00	3,750	
11.00	4,250	10,000,000
6.00 lowest point in lake	5,250	1,000,000

There was in the lake on April 15 about 365,000,000 gallons of water containing 3,000,000 pounds of sodium chloride, or its equivalent, and 4,200,000 pounds of other salts. Of the sodium chloride 2,200,000 pounds were contained in approximately 11,000,000 gallons of water, below elevation 15. This quantity lies in numerous deep pockets below gradient of the old stream bed.

The specific gravity of the water below elevation 10 was 1.008, there was perhaps a million gallons of this.

The water between elevation 10 and 15 (10,000,000 gallons) S. G. = 1.005.

Water between elevation 15 and 21, S. G. = 1.002.

From these facts it was evident that unless each individual deep pocket was pumped out separately, 66 per cent of the salt present could not be directly affected by any amount of pumping.

Diffusion was arrested and the water remained stratified whenever the Cl in the surface layers reached 500 p.p.m. approximately.

It was figured from this data, that if all the water above the gradient of the stream bed, were displaced by fresh water, there would again be 500 p.p.m. of chlorine in the surface water as soon as equilibrium was reëstablished up to the point where diffusion seemed to be arrested, and that only on the third complete displacement could the water be expected to come again within the limits of potable water.

It was concluded that the only way to get satisfactory water within a reasonable time was to drain the lake completely, using the running river water above as a supply in the meantime.

In the meantime work previously planned had been going forward and the spillway had been raised 8 feet. With this increased volume of water a new equilibrium was established, the surface water taking chlorine to the extent of 150 p.p.m.

Before we could put our plans for draining the lake into operation the situation was relieved by a torrential, cold rain. The temperature of the river water flowing into the lake was 4°C. below that of the lake water. The difference in gravity, due to temperature, overcame the difference due to the presence of the salt, permitting the cold fresh water to slip in, as it were, between the lighter salty strata in the upper levels of the lake and the dense salt solution at the bottom. This fresh water settling directly on top of the strong salt solution absorbed the salt very rapidly. The vertical distribution of Cl a few days after the storm is shown below and at the right a hypothetical condition which must have occurred in the interim:

ELEVATION ABOVE SEA LEVEL	TEMPERATURE DEGREES C.	CHLORINE P. P. M. OBSERVED	HYPOTHETICAL
41.7	30	150	150
34.7		130	150
31.7	28	110	150
24.7	26	70	
18.7	26	80	000*
16.7	26	140	
15.7	26	560	1,300
12.7		3,000	3,000
5.7		5,250	5,250

*Indicates that a stratum of water, of indeterminate thickness and position, was for a time free from chlorine though suspended between two strata of salt water.

Previous to this rain a drainage pump of 16,000,000 gallons daily capacity had been in operation, 12 hours a day, for six days. The record of chlorine in the discharge from this pump at 24-hour intervals follows; 1000 p.p.m., 850, 750, 650, 550, 450. Here the storm referred to occurred and the chlorine in the pump discharge dropped to 100, coming back to 250, it again settled to 140 where it remained, the whole lake above elevation 16 now being uniform at that figure. Pumping was then stopped as nothing could be gained by pumping that could not be as well accomplished by letting the water waste over the spillway.

On July 31 it was estimated that there still remained in the lake 1,250,000 pounds of (sodium) chloride as against 3,000,000 pounds on April 15. The removal of the difference had been as follows:

	(Sodium) Chloride pounds
Removed by small drainage pump March 25 to May 4	1,277,000
Removed by regular consumption April, May, June and July	642,000
Removed by large drainage pump July	296,000
Estimated remaining July 31	1,249,000

NOTE. Approximately 614,000 pounds had been removed by small pump previous to estimate of April 15.

As to how small a quantity of chlorine in a water will make it taste salty, there were differences of opinion, when water containing sodium chloride to the amount of 350 p.p.m. was given to the various laboratory employes. Less than this quantity was not detected. However, sea water added to tap water to give 200 p.p.m. Cl was very unpleasant to most persons.

Some persons complained of a nauseating and burning sensation of the stomach when using water with over 200 parts of chlorine. The writer experienced this several times when the water was not thoroughly iced.

No more serious effects on the human system were observed, although water with from 200 to 400 parts Cl was delivered regularly for three months.